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Brian A. Westfall[1]
W. Kirsch & G. Looby[2]

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16. ABSTRACT
Many metal finishing facilities are small businesses which lack in-house expertise or resources to initiate waste minimization programs. In 1988 the Risk Reduction Engineering Laboratory began a pilot project with the University City Science Center to provide waste minimization assessments for small businesses at no out-of-pocket expense to the host facility. Several metal finishing operations were included among the plants visited. The results of waste minimization assessments at two of these plants are discussed. The recommended waste minimzation options and the actual experience with implemented recommendations are presented.

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by

Brian A. Westfall
U.S. Environmental Protection Agency
Cincinnati, Ohio

W. Kirsch and G. Looby
University City Science Center
Philadelphia, Pennsylvania

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Brian A. Westfall
Pollution Prevention Research Branch
U.S. Environmental Protection Agency
26 West Martin Luther King Drive
Cincinnati, Ohio 45268

and

F. William Kirsch and Gwen P. Looby
Industrial Technology and Energy Management
University City Science Center
3624 Market Street
Philadelphia, Pennsylvania 19104

Introduction

Waste minimization and pollution prevention are becoming familiar terms to today's business leader. Successful application of waste minimization principles is proving that profitability can be enhanced as waste generation is reduced or eliminated. Waste treatment and disposal can be expensive if done properly and very expensive if done improperly. Avoiding the current costs and future liabilities of waste management sounds great, but how does the small business get started in the right direction? How does the company which has already implemented the obvious measures move further along? The USEPA promotes the use of periodic waste minimization opportunity assessments to help initiate and continue a permanent, effective waste minimization program. Several mechanisms have been developed by the Federal and state governments to assist businesses interested in adopting waste minimization as a primary waste management strategy. One such mechanism is the Waste Minimization Assessment Center (WMAC) pilot project performed by the University City Science Center and funded by the USEPA.

Project Description

The USEPA has produced and published the Waste Minimization Opportunity Assessment Manual (EPA/625/7-88/003, July 1988) which describes a generic procedure for conducting a waste minimization assessment at an industrial facility. The direct use of this manual at a small business lacking in-house resources or expertise may be impractical. A pilot project providing waste minimization assessments to qualifying businesses at no out-of-pocket expense was initiated at the University City Science Center in Philadelphia, Pennsylvania. Two WMACs were established in the first year of the project - one at the University of Tennessee in Knoxville, and one at Colorado State University in Fort Collins. A third center at the University of Louisville (Kentucky) was added later. The WMACs send teams composed of faculty and student members to businesses fulfilling at least two of the following criteria:

1. Gross annual sales of not more than $50 million.
2. No more than 500 employees.
3. Lack of in-house expertise in waste minimization.

The WMAC team schedules a series of visits to each facility and provides each client a site-specific confidential report summarizing their findings and recommendations, including projected implementation costs, cost savings and simple payback times.

Implementation of the waste minimization recommendations is the responsibility of the client manufacturer. No USEPA funding is currently available nor foreseen for implementing recommendations under this project. Each facility is visited within one year to obtain actual cost and savings information on implemented recommendations. In addition, the factors determining whether or not a particular recommendation was implemented are discussed with the client. During the first year of the project, 12 assessments were completed. The implementation rate for the 87 recommendations was 52%, and 49% of the overall potential dollar savings are being attained.

Case Studies

Facility A is a manufacturer of compressed air equipment components. The manufacture of compressed air equipment components begins with the fabrication of zinc and aluminum diecast parts. Zinc and aluminum alloy ingots are melted in separate furnaces and the molten metals are then transported to diecasting machines. The diecasting machines force the liquid metals into a mold-and-plunger assembly by hydraulic compression. A water-based lubricant is sprayed on the molds, and an oil-based lubricant is used for the plunger. Excess lubricants collect in a sump and are mixed with other oil wastes for disposal. Small amounts of solvent used to clean the diecasting machines are also mixed with the oil wastes. An ethylene glycol/water-based hydraulic fluid provides the required hydraulic compression. Extensive leakage in the hydraulic fluid reservoir requires that fresh hydraulic fluid be added to maintain the proper fluid level. Used fluid is mixed with the miscellaneous oil and solvent wastes for disposal. Solid wastes in the diecasting area consist of scrap and excess metal, which is remelted in the proper furnace along with the raw metal ingots.

Diecast metal parts are transported to the machining area to be milled, drilled, and tapped as required. Most of the machining equipment uses a water-based cutting/cooling fluid. A centrifuge removes metal contaminants so that the fluid may be reused. Solids and sludge that remain are mixed with oil and solvent wastes for disposal. Some of the machining equipment uses an oil-based lubricant; no liquid wastes are generated from these machines because the oil is recycled. Occasionally, lubricants are added to compensate for lubricant that remains on the metal parts. Small amounts of solvent used to clean the machines are mixed with the oil wastes. Oil-contaminated metal shavings from the machining area are sold to an outside firm for reuse.

After machining, parts are washed with an alkaline solution containing borax to remove remaining cutting oil and are deburred before application of protective coatings. Oil is collected by a skimmer in the alkaline washer and mixed with the water-based lubricant from the machining area. Effluent from the washer is combined with other aqueous wastes that flow to an on-site wastewater treatment unit.

Steel parts that have been manufactured at an off-site facility are cleaned in a small vapor degreasing unit with 1,1,1-trichloroethane. Waste solvent and still bottoms from the vapor degreaser are drummed and disposed of as hazardous waste.

Surface coatings are applied to all metal parts. Chromate conversion, phosphate, or anodized coatings are applied by immersing the parts in a series of chemical baths and rinses. The chromate conversion coating line is automated, and the phosphate and anodized coating lines are operated manually. The actual treatment process varies for each metal coated. Effluents from the coating lines and alkaline washer are combined and treated in the wastewater treatment facility. Sodium metabisulfite is added to reduce hexavalent chromium to trivalent chromium. Sodium hydroxide is then added to raise the pH from about 2.75 to 8.5 and to form insoluble metal hydroxides. Adding calcium chloride removes sulfate and phosphate ions as insoluble calcium compounds. Precipitates are flocculated with a polymer and allowed to settle to form a metal hydroxide sludge, which is periodically pumped to a filter press for dewatering and shipped to a hazardous waste disposal facility. The supernatant's contaminant level is below the pretreatment specifications of the local POTW, so it is discharged to the sewer system.

Powder coating is applied to some of the metal parts, which are then cured in a furnace. No hazardous waste is generated in the powder coating process. Plastic injection molding machines, which use an oil-based hydraulic fluid, produce the plastic components of the compressed air equipment. The hydraulic fluid is filtered periodically and reused. Contaminated fluid is mixed with other oil and solvent wastes for disposal.

Hazardous wastes are also generated in processes not directly related to manufacturing. The tooling area, where molds and equipment are maintained, contains equipment that employs the same water-based cutting/coolant fluid used for machining. This fluid is also reused after processing with the centrifuge. The clean room generates about 10 gal/mo of waste chlorofluorocarbons from cleaning components to be used for medical and other special applications; the waste is sent off-site for disposal. Small amounts of solvent-based paints are used for machinery, and any waste is sent off-site for disposal.

Before the WMAC's team assessment, the plant had already taken the following steps to minimize and manage its generation of hazardous wastes:

- Using a centrifuge to remove metal chips and fine particles from the water-based coolant/cutting fluid used in the machining area. The

clean fluid is then collected and reused.

- The plant plans to eliminate on-site treatment of steel parts; this will reduce or eliminate the need for solvent degreasing and also the need to dispose of contaminated 1,1,1-trichloroethane.

- Using an alkaline wash to remove oil from metal parts before surface treatment. This alkaline wash replaced more traditional cleaners, such as halogenated organic compounds.

- Using a filter press to reduce the water content of the hazardous metal hydroxide sludge before shipment off-site for disposal.

- Using powder coatings on metal parts. Replacing solvent-based paints with powder coatings eliminated solvent-based paint wastes and reduced the emission of volatile organic compounds.

- Collecting metallic wastes from the diecasting process and remelting them in the appropriate furnace. Oil-contaminated metal chips from the machining area are collected and sold to a metal recycler.

- Minimizing the use of solvent-based paints for general painting. Solvent-based paints are only used on machinery and other items not suited for water-based paints.

Table 1 summarizes the principal sources of waste, the amounts generated, and the associated management costs. Table 2 briefly describes current plant practices, the recommended waste minimization opportunities, and savings and cost data.

The WMAC also investigated several other opportunities for waste minimization that require relatively lengthy paybacks or are considered to be beyond the scope of this program. These measures are:

- Implementing a preventative maintenance program for the diecasting machinery to reduce the frequency and cost of unscheduled repairs.

- Establishing a program to segregate oil wastes to allow recycling of waste oils.

- Using a water/glycol fluid instead of a petroleum-based fluid as the hydraulic fluid in the plastic injection molders. The water/glycol fluid would reduce waste generation because of its longer lifetime.

- Installing a solvent recovery unit to remove contaminants from the 1,1,1-trichloroethane used in the vapor degreasing unit.

- Using deionized water in the reagent baths in the chromate conversion coating line.

- Removing waste oil from the wash water from the alkaline cleaner.

Table 1. Summary of Current Waste Generation

Waste stream	Waste generated	Annual quantity generated, gal	Annual waste management cost
Die casting	Combined wastes including water-based die lubricant, oil-based plunger lubricant, water-soluble cutting/cooling fluid, water/glycol hydraulic fluid, and equipment cleaning solvents.	9,660	$ 5,300
Plastic molding	Combined wastes including petroleum-based cutting/cooling fluid, water-soluble cutting coolant, water/glycol hydraulic fluid, and equipment cleaning solvents.	1,780	980
Machining of die cast parts	Combined wastes including petroleum-based and water-based cutting/cooling fluids and equipment cleaning solvents.	18,060	9,920
Vapor degreaser unit	1,1,1-trichloroethane and still bottoms.	350	1,750
Treatment of rinse water from the coating operation and the alkaline washer	Rinse water laden with heavy metals and reagents used in chromate conversion coating, phosphating, and anodizing.	2,930,000	4,900
Cleaning of parts used in special applications	Waste chlorofluorocarbons.	100	130
Painting of plant equipment	Waste solvent-based paint and thinner.	400	2,560

Table 2. Summary of Recommended Waste Minimization Opportunities

Present practice	Proposed action	Cost savings
Reagents used to create a conversion coating on aluminum parts contain chromium and therefore generate hazardous waste. These reagents contaminate rinse water and contribute to the amount of hazardous solid waste that is generated.	Replace the chromium-containing reagents with reagents that generate no hazardous waste. The proposed coating process does not require rinsing after coating and therefore will not contaminate rinse waters.	Solid waste reduction = 1280 gal/yr Liquid waste reduction = 659,300 gal/yr Cost savings = $5,480/yr Implementation cost = $0 Payback is immediate.
Oil wastes from the die casting, injection molding, and machining areas are combined and form a multiphase fluid that is sent to a disposal facility.	Use magnesium chloride as a de-emulsifying agent to break the oil-water emulsion. The oil waste can be collected in a tank and sent to an oil recycler. The aqueous phase can be treated at the plant's wastewater treatment facility.	Waste reduction = 16,230 gal/yr Cost savings = $6,820/yr Implementation cost = $2,500 Payback = 0.4 years
Drainage time over reagent baths in the chromate conversion coating line is 5 sec.	Increase the drainage time to 10 sec to allow more reagent to drain back into the bath. Waste reduction will result from extended lifetimes for the baths.	Waste reduction = 17 gal/yr Cost savings = $210/yr Implementation cost = $0 Payback is immediate.

Facility B is a printed circuit board manufacturer. Laminated flat sheets of nonconducting material are first cut to a size slightly larger than the desired end product, then drilled by programed high-speed drills, and finally deburred at the holes and board edges by rotating brushes. A thin layer of copper is deposited by electroless plating on boards that are first cleaned and rinsed and then coated with a catalyst for the reduction of the copper. To apply the circuit patterns, a dry film process is used--laminating a photosensitive polymer resist, covering parts of the board with the printed circuit design mask before exposure to ultraviolet light, developing with sodium carbonate, and eventually rinsing with tap water.

Electrolytic plating of copper occurs on the circuit design developed in the preceding series of operations. Then tin is electrolytically plated on the copper to protect the circuit design from the alkaline etchant used to strip away the plating resist. Any copper not protected by tin is also etched away by an alkaline solution. Finally, an ammonium bifluoride/hydrogen peroxide solution removes the tin to complete the electronic circuitry on the board, which is then water-rinsed and air-dried. The principal remaining step is to apply solder to the desired areas, which are the portions of the boards not coated by an epoxy solder mask, which also functions as an insulator. Then a eutectic solder is coated on the areas not covered by the mask. To meet certain customers' specifications, connectors are sometimes gold plated before solder mask application.

Actions already taken by this plant to reduce hazardous wastes include:

- Using dry film photoresist to eliminate chlorinated solvents associated with silk screen application.
- Substituting tin for lead solder after electrolytic copper plating (though a small amount of tin/lead solder is required as a final coating).
- Combining an automated electroless plating machine with countercurrent rinsing to cut down drag-out of plating solution and to reduce the quantity of rinse water.
- Agitating these rinse tanks with compressed air to get better rinsing in a given tank volume.
- Using deionized water in the electrolytic plating lines to lessen the formation of sludge (hard-water deposits).
- Converting to plastic covered racks for those same electrolytic plating lines to reduce (by 75%) the amount of stripping solution needed to remove excess copper and tin deposits on the racks.
- Applying mechanical deburrers, scrubbers, and hot-air dryers to eliminate some hazardous solvents. (The dusts from these operations are collected and sold to a metal reclaimer.)

Most of the hazardous waste generated in this plant occurs in various liquid streams. The main sources of metallic contamination are the rinses after scrubbing, plating, and etching. Dissolved cooper occurs in the rinses following etching and plating, in the accelerator and acid activator baths on both plating lines, and in the alkaline etch and rack stripping solutions. Metallic copper is generated by mechanical cleaning operations, drilling and routing operations, and cutting operations. Tin comes from electrolytic plating and stripping; lead, from rinsing and deburring.

Rinse streams discharged to the sewer because they are not considered hazardous are those from the dry film developer, the post-clean rinse, the gold plating rinse, and the spent resist stripper. The other rinses and dumps are directed into a large trench with a level controller which activates a pump to transport the liquids to a treatment system that utilizes chemical reactions, precipitation, and membrane filtration. Suspended solids in an associated concentration tank are removed by bleeding a "slip stream" to a settling tank, from which sludge is dewatered to about 60% solids before it is hauled to a disposal site for hazardous wastes. Table 3 is a summary of the major waste streams and associated waste management costs.

Eight waste minimization opportunities are summarized in Table 4, together with the projected reductions in emissions and the associated savings and costs. The savings are calculated for each recommendation independently, but some are related such that the results from implementing one can affect the results calculated for another independently. It should also be noted that cost savings can often be achieved through operations such as filtration, precipitation, flow reduction, and concentration of solutions and suspensions. These, along with deionization and reagent substitution, are readily available and can be highly effective tools in efforts to reduce waste emissions and to lower costs.

Conclusions

Waste minimization opportunity assessments are valuable components of on-going waste minimization programs. The assessment procedures in EPA's Manual are very effective, but may be impractical for small businesses lacking in-house expertise. A positive experience with a technical assistance team can provide immediate opportunies for cost-effective waste minimization activites, usually resulting in a commitment to waste minimization as the primary waste management strategy.

Table 3. Summary of Current Waste Generation

A. HAZARDOUS LIQUID WASTES

Waste stream	Waste generated	Annual quantity generated (gallons)	Annual waste management cost		
			Treatment	Disposal	Recycling
Electroless copper:					
Waste rinses	Copper plating and drag-out	516,663			
Catalyst predip	Table salt/water dumps	530			
Accelerator	Copper-laden, dilute hydrochloric acid	530			
			$10,488	$ 587	
Electrolytic copper:					
Acid soap preclean	Acid soap dumps	10,189			
Water rinses	Soap, etch, copper & tin plating drag-out	366,665			
Copper plating predip	10% sulfuric acid dumps	3,266			
Tin plating predip	2% sulfuric acid dumps	3,266			
			$ 4,380	$ 246	

(continued)

Table 3. (continued)

Waste stream	Waste generated	Annual quantity generated (gallons)	Annual waste management cost		
			Treatment	Disposal	Recycling
Resist strip, copper etch, and tin strip:					
Water rinses	Etch, resist and tin strips drag-out	549,997			
Alkaline etch	Spent ammonium hydroxide	13,950			
Tin strip	Spent ammonium bifluoride/ peroxide	1,450			
Rack stripper	Spent rack stripper	1,550			
			$ 6,285	$ 352	$45,765
Other processes:					
Deburrer #1	Copper-laden rinse water	366,665			
Deburrer #2	Copper-, tin/lead-, and gold-laden rinse water	366,665			
Scrubber	Epoxy-, tin/lead-laden rinse water	183,332			
Hot air leveling	Copper-, ferric chloride-, and hydrochloric acid-laden rinse water	183,332			
			$12,570	$ 704	

(continued)

Table 3. (continued)

B. HAZARDOUS SOLID WASTE

Waste stream	Waste generated	Annual quantity generated (pounds)	Annual waste management cost
Wastewater treatment system	Metal hydroxide sludge	27,700	$5,471
Electroless copper:			
Microetch	Copper sulfate crystals	2,800	
Drilling and routing	Copper, aluminum, and gold dust	200	
Deburrer #1	Metallic copper	200	
Shearing	Copper/epoxy laminate dropoffs	1,200	
Filters:			
Electrolytic copper	Nonhazardous filter cake	25	
Post clean	Tin/lead-laden filters	25	
Auto tab plater	Gold-laden resin filter cartridges	25	

Table 4. Summary of Recommended Waste Minimization Opportunities

Present practice	Proposed action	Cost savings
Effluent from the wastewater treatment system is sewered.	Reuse the treatment system effluent to reduce demand for rinse water. To widen the range of possible uses, some further treatment (e.g., ion exchange, adsorption, filtration) may be needed. Additional storage tanks, pumps, and piping will be required. Saving occurs in lower water demand and sewer charges.	Waste reduction = 1,833,325 gal/yr Cost savings = $3,840/yr (net) Implementation cost = $22,000 Simple payback = 5.7 yr
The scrubber uses 183,300 gal/yr to rinse particulates from circuit boards. The liquid containing particulates goes to the wastewater treatment system.	Filter (in a closed loop system) scrubber liquids to remove hazardous particulates and recycle the water for rinsing the scrubber. Dispose of filter cartridge as solid hazardous waste.	Waste reduction = 183,300 gal/yr Cost savings = $2,150/yr (net) Implementation cost = $650 Simple payback = 4 mo
Thorough rinsing is manadatory for many operations in this plant. Observation of the plant revealed high water flow rates.	Install flow reducers or flow meters on the water supply to seven identified manufacturing operations. Waste reduction and cost savings are calculated only for reduced water, treatment, and sewer usage.	Waste reduction = 440,000 gal/yr Cost savings = $5,840/yr Implementation cost = $360 Simple payback = less than 1 mo
The particular brand of dry film developer in use adheres so strongly to the unexposed film that an aggressive acid soap is required for removal. This soap presents problems in the wastewater treatment unit and requires conditioning agents.	Change to another dry film developer, use a less aggressive soap (also nonhazardous), and discharge the liquid to the sewer after pH adjustment.	Waste reduction = 13,500 gal/yr Cost savings = $23,550/yr (based on conditioner use alone) Implementation cost = 0 Simple payback = immediate

(continued)

Table 4. (continued)

Tin is stripped away from the electrolytically deposited copper sites that it protects. A solution of ammonium bifluoride and hydrogen peroxide is the stripping agent. The relatively large quantity of washes is sent off-site for treatment and recovery of tin.	Concentrate the tin stripping solution to reduce hauling and treatment costs. Partial freezing will cost less than evaporation. The metal reclaimer has said the concentrate is acceptable, and there will be no increase in unit costs of hauling and recycling. The separated solid can be melted and sewered.	Waste reduction = 1,650 gal/yr Cost savings = $4,030/yr (net) Implementation cost = $10,000 Simple payback = 2.5 yr
Deionized water is used for rinsing on the electrolytic copper and tin plating lines. Its use should be extended to the electroless copper plating line.	Use deionized water in five baths in the electroless copper plating line, thereby reducing sludge formation and extending the lifetime of the bath. The savings will be achieved in lower cost of treatment chemicals, as well as in lower water and sewer costs. Use an ion-exchange regeneration system.	Waste reduction = 1,015 gal/yr Cost savings = $1,840/yr Ion-exchange saving = $6,500/yr Implementation cost = $9,800 Simple payback = 1.2 yr
Solid copper waste is collected from the deburrer and copper sulfate from the microetch solution.	Improve the collection of copper and send the copper sulfate for recovery instead of storing it.	Waste reduction = 3,200 lb/yr Cost savings = $700/yr Emplementation cost = 0 Simple payback = immediate
Plant operators hold drip racks over certain baths to reduce the quantities of drag-out. Times and drainage vary widely.	Install drip racks over the electrolytic plating baths, the acid soap bath, and the microetch bath. Lower consumption of plating reagents, copper nuggets, and tin anodes will result.	Waste reduction = 10 gal/yr Cost savings = $275/yr Implementation cost = $200 Simple payback = 9 mo